Energy Management Initiative – Wave 4

Activated Sludge: Understanding the Process and Satisfying Oxygen Needs

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Objectives of Biological Treatment

- Oxidize dissolved and particulate biodegradable constituents into acceptable end products
- Capture suspended and nonsettleable colloidal solids into a biological floc or biofilm
- Transform or remove nutrients such as N and P
- Remove specific trace organic compounds

Primary reference: Metcalf & Eddy 4th Edition

Definitions: Metabolic Functions

- **Aerobic processes** – biological treatment processes that occur in the presence of oxygen
- **Anaerobic processes** – biological treatment processes that occur in the absence of oxygen
- **Anoxic processes** – process by which nitrate-N is converted biologically to nitrogen gas in the absence of oxygen

Definitions: Treatment Functions

- **Nitrification** – two-step biological process by which ammonia-N is converted to nitrite-N and then to nitrate-N
- **Denitrification** – biological process by which nitrate-N is reduced to nitrogen and other gaseous end products

Roles of Microbes in Wastewater Treatment

- **Oxidation of organic matter** in wastewater is accomplished biologically using a variety of microorganisms, primarily bacteria

$$\text{Organics} + O_2 + NH_3 + PO_4 \xrightarrow{\textbf{microbes}} \text{New cells} + CO_2 + H_2O$$

- **New cells** represent the biomass produced as a result of oxidation of the organic matter

Roles of Microbes in Wastewater Treatment

- Microbes are also used to remove N and P in wastewater treatment processes
- Nitrifying bacteria can convert ammonia-N to nitrite-N and nitrate-N
- Denitrifying bacteria can convert nitrate-N to gaseous nitrogen
- In biological P removal, bacteria take up and store large amounts of inorganic P

Nitrification: Biochemical Reactions

$$2NH_4^+ + 3O_2 \longrightarrow 2NO_2^- + 2H_2O + 4H^+ + \text{new cells}$$

$$2NO_2^- + O_2 \longrightarrow 2NO_3^- + \text{new cells}$$

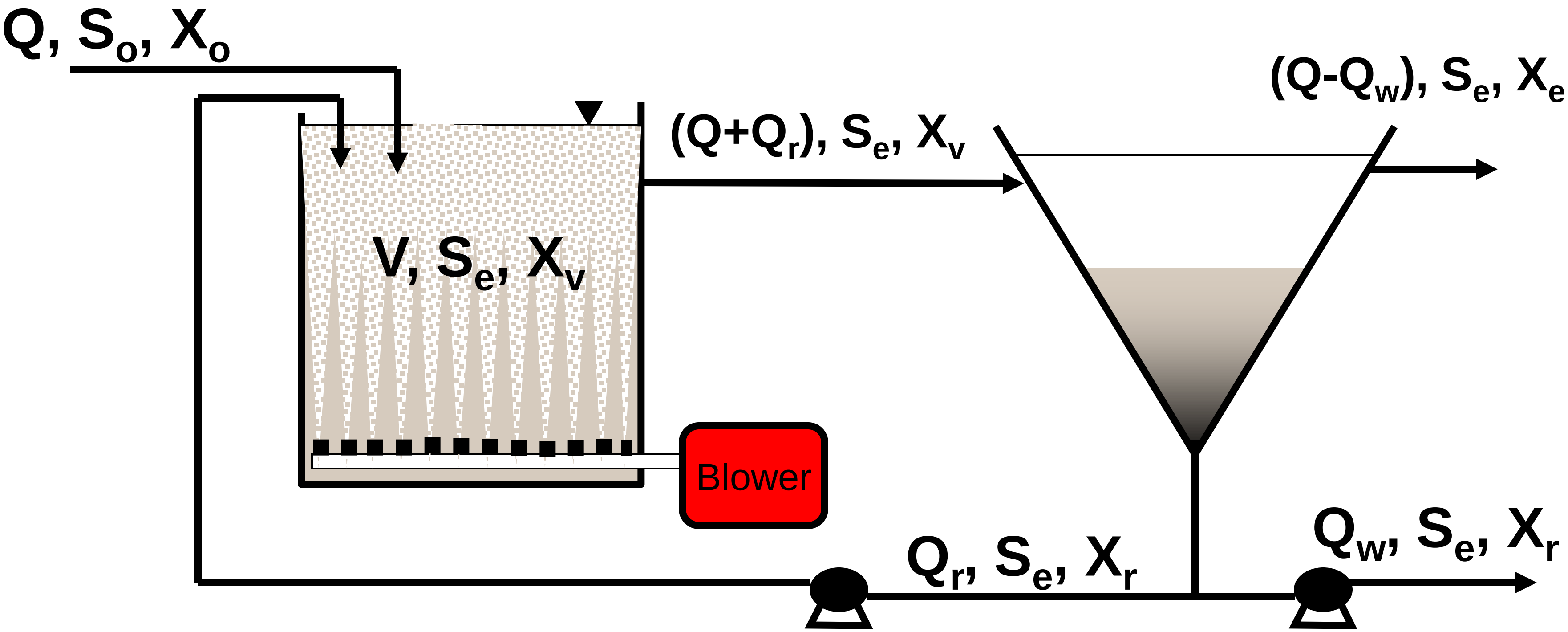
The overall reaction is:

$$NH_4^+ + 1.83O_2 + 1.98HCO_3^- \longrightarrow 0.98NO_3^- + 0.021C_5H_7O_2N + 1.88H_2CO_3 + 1.04H_2O$$

Comments about Activated Sludge

- In aeration tank, contact time is provided for mixing and aerating influent wastewater with microbial suspension (mixed liquor)
- Mechanical equipment is used to provide mixing and oxygen transfer
- Mixed liquor flows to secondary clarifier where biomass is separated from the treated wastewater and is thickened
- Settled biomass is returned to aeration tank to continue biodegradation of influent organic material

Activated Sludge: Basics of Design



An Example of Equipment at a Modern Activated Sludge Facility

Remember:

θ_c = MCRT = SRT = sludge age

It is how long in days (on average) the biomass stays in the activated sludge system until the biomass exits the system as waste activated sludge solids or as TSS in the effluent.

Activated Sludge Design

μ_{max} = maximum specific growth rate

K_s = saturation constant

k_e = microbial decay coefficient ($k_e = k_d$)

Y = biomass yield constant

k = maximum specific substrate utilization rate

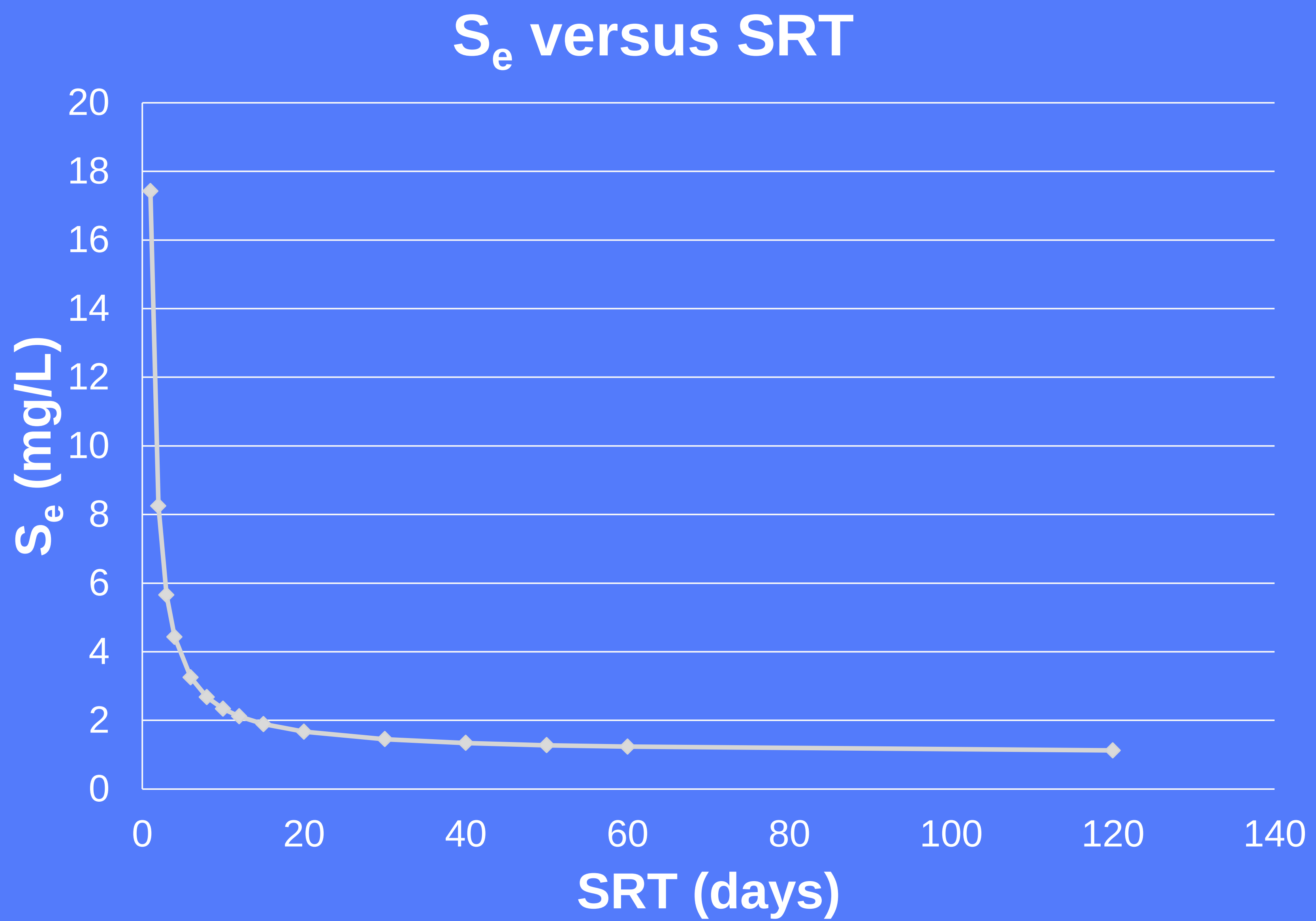
$\mu_{max} = Yk$

Determining S_e Using Biokinetic Approach

$$S_e = \frac{K_s(1+k_e\theta_c)}{\theta_c(\mu_{max}-k_e)-1}$$

S_e does not include $CBOD_5$ contributed by solids.

This equation is only valid for *Monod kinetics.*

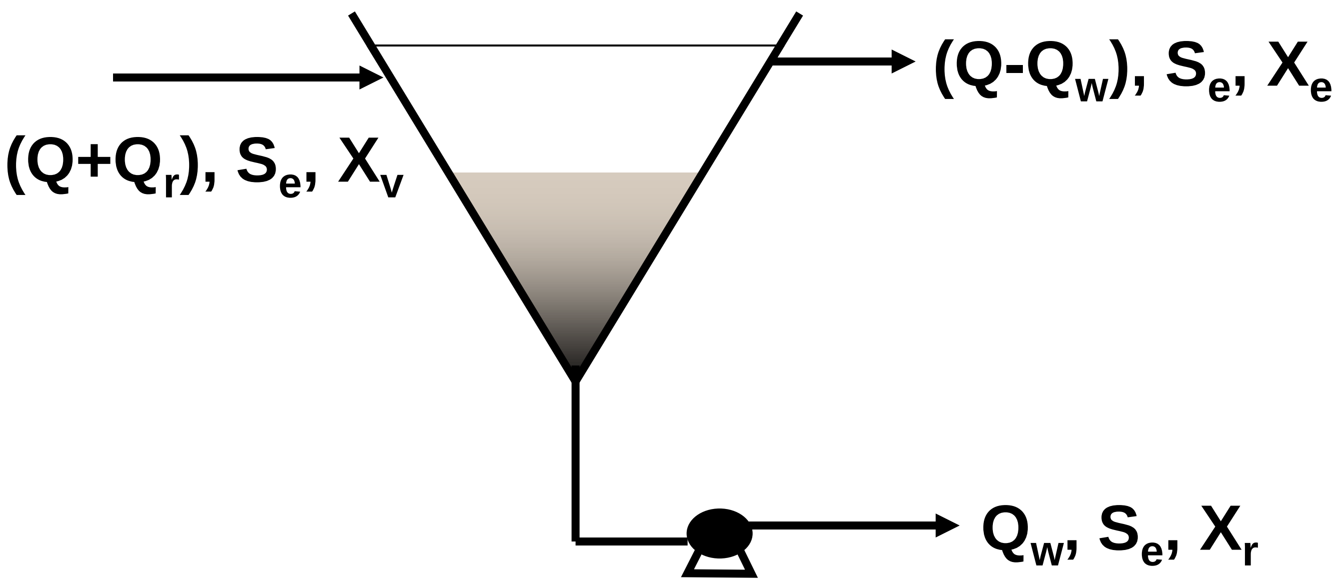

Se versus SRT
20
18
16
14
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Se (mg/L)
SRT (days)

Activated Sludge Design

Step 1: **Determine effluent requirement**

$$CBOD_{5eff} = S_e + f\, X_e$$

where X_e = TSS in final effluent
S_e = soluble $CBOD_5$
f = g $CBOD_5$/g TSS = 0.3 to 0.6



Activated Sludge Design

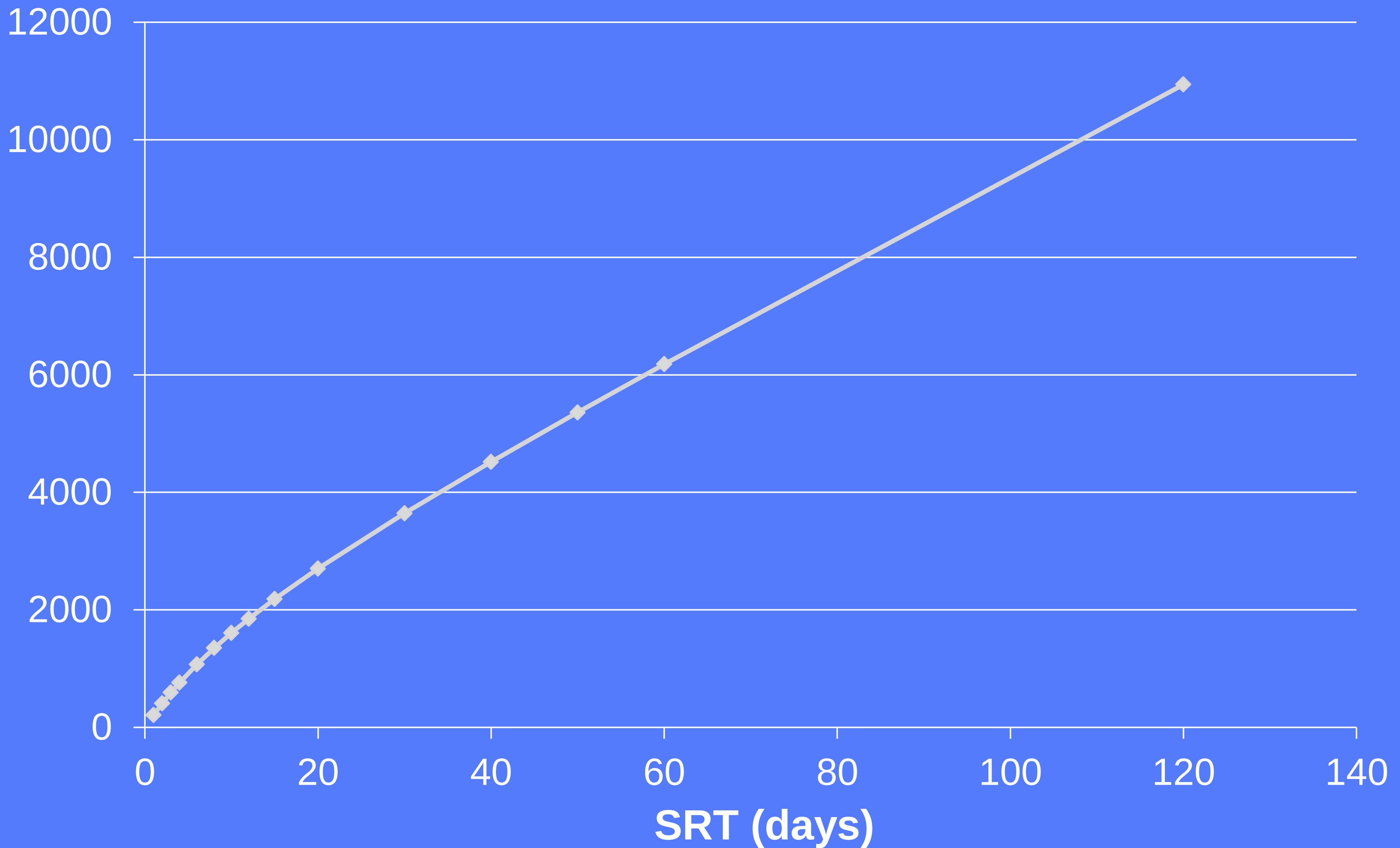
Step 2: Select MLVSS concentration in aeration basin.

Xv = 1500 to 3000 mg/L for complete mix
1500 to 4000 mg/L for extended air

Step 3: Determine aeration basin volume

$$V = \frac{QY_{x/s}\theta_c(S_o - S_e)}{X_v(1 + k_e\theta_c)}$$

MLSS versus SRT – 1.0 mgd Extended Aeration Act. Sludge



Activated Sludge Design

Step 4: Determine the mass of volatile solids to be wasted (Pxvss)

$$P_{XVSS} = A + B + C$$

A + B = biomass production = VSW

A = heterotrophic biomass
B = cell debris
C = nonbiodegradable VSS in influent

$$P_{XVSS} = \frac{QY(S_o - S_e)}{1 + k_d\theta_c} + \frac{f_d(k_d)YQ(S_o - S_e)\theta_c}{1 + k_d\theta_c}$$

$$+ \; QX_{oi}$$

Activated Sludge Design

Step 5: Determine the mass of **total** solids to be wasted (Px)

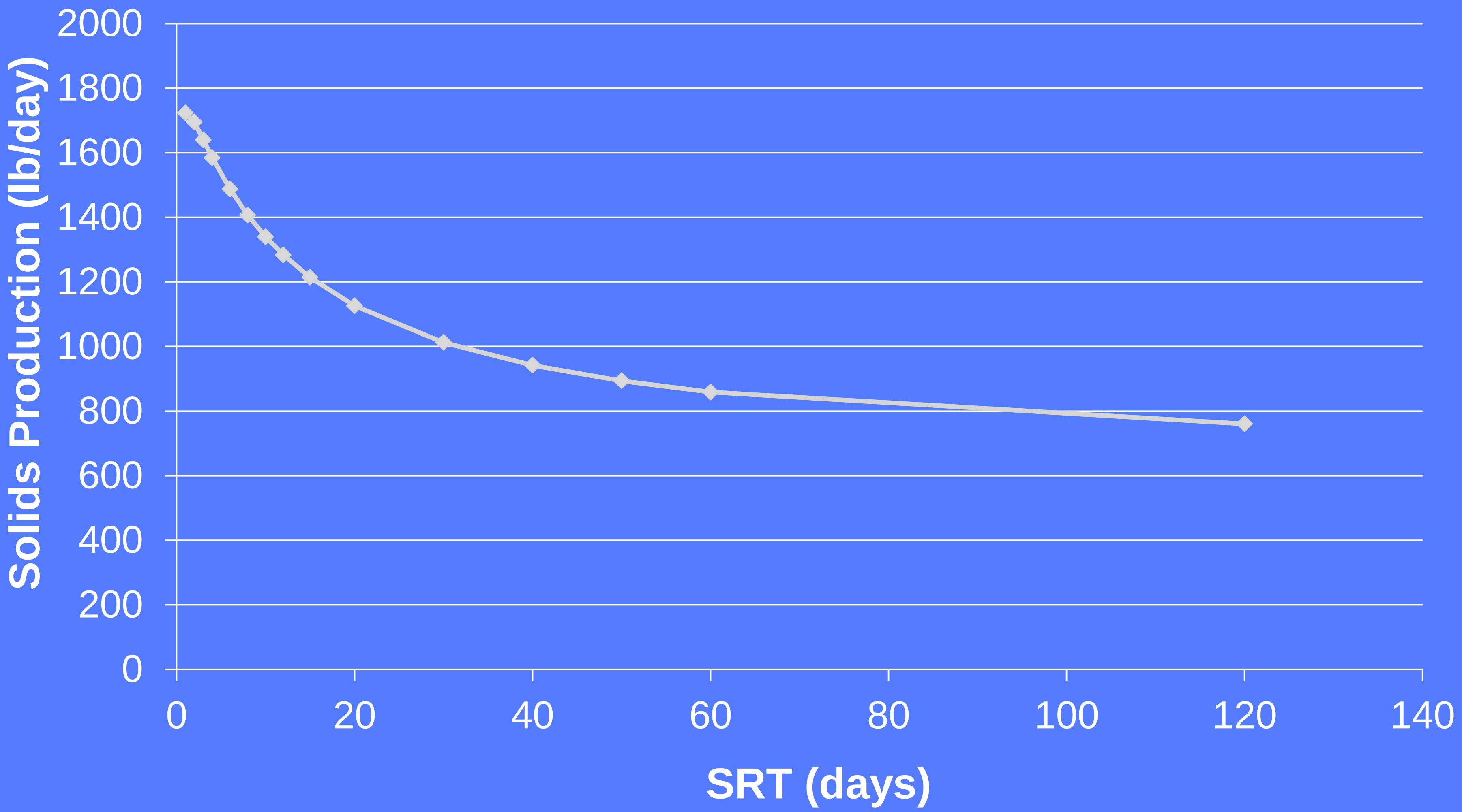
$$P_{XTSS} = A/0.85 + B/0.85 + C + Q(TSS_o - VSS_o)$$

where P_{XTSS} = net waste activated sludge produced each day, mass/day

TSS_o = influent TSS concentration

VSS_o = influent VSS concentration

Sludge Production (TSS, lb/d) vs SRT - 1.0 mgd Extended Aeration Act. Sludge



Activated Sludge Design

Step 6: Determine the oxygen requirements (CBOD and NBOD)

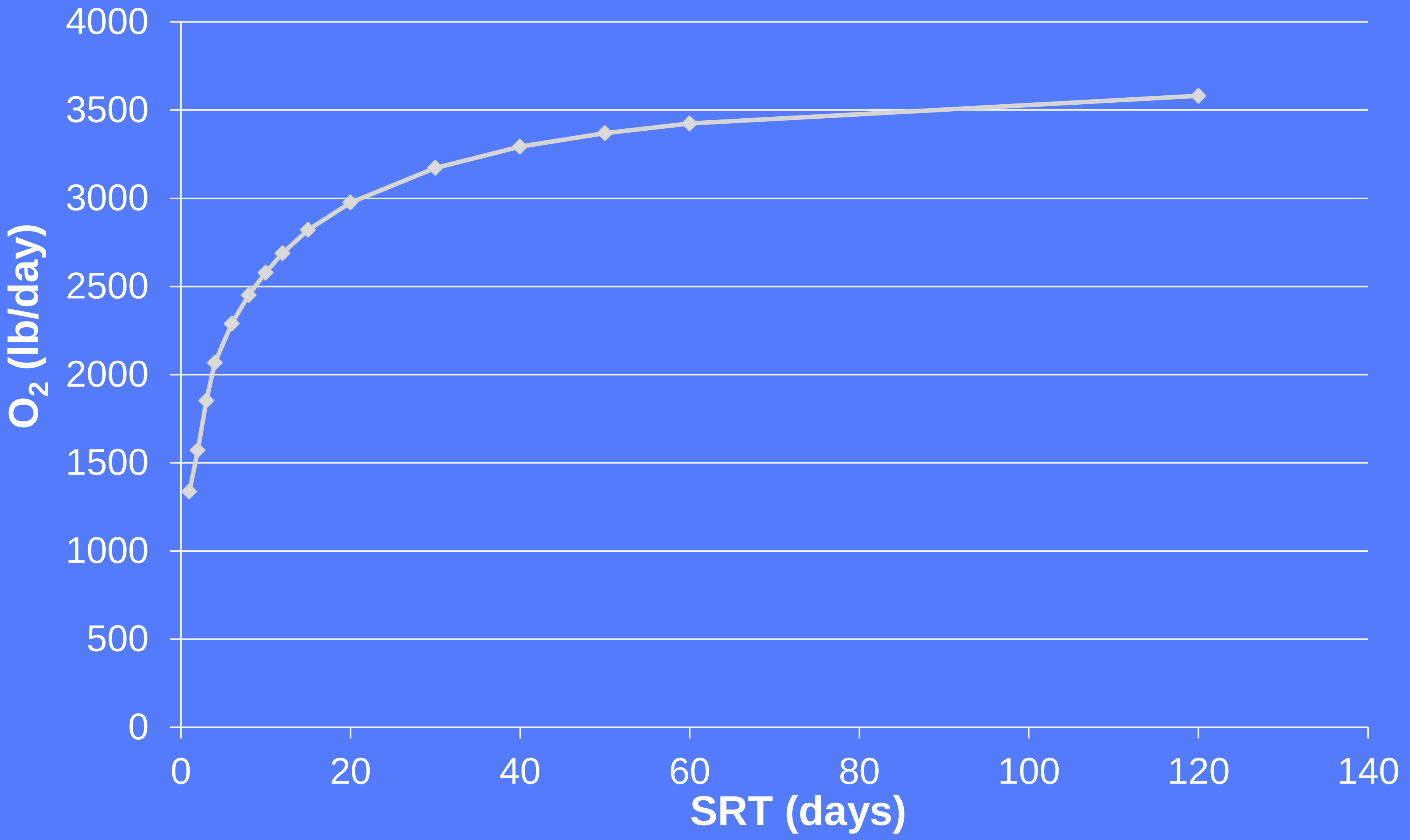
$$O_2(\text{lb/day}) = 8.34Q\left[\frac{S_o - S_e}{0.67}\right] - 1.42(VSW)$$

$$+ 4.33(N_{ox})(Q)(8.34)$$

*Note: VSW = biomass production = A + B in previous equations

1.42(VSW) = ultimate CBOD that goes to cell growth

Oxygen Required (Carb+Nit) vs SRT – 1.0 mgd Extended Aeration Act. Sludge



Approximate Field O_2 Transfer Rates

- Pump type aerators
  - 1.4 to 2.1 lb O_2/(HP-hr)
- Aspirating aerators
  - 1.0 to 1.4 lb O_2/(HP-hr)
- Horizontal rotor aerators
  - 1.5 to 2.1 lb O_2/(HP-hr)

α = 0.84, β = 0.92, ρ = 1, DO = 2 mg/L, Elevation < 500 ft

Approximate Field O_2 Transfer Rates

- Nonporous diffusers
  – 1.0 to 1.5 lb O_2/(HP-hr)
- Porous diffusers
  – 1.7 to 2.4 lb O_2/(HP-hr)

α = 0.84, β = 0.92, ρ = 1, DO = 2 mg/L

Elevation < 500 ft, Compressor efficiency = 75%

Tank depth = 15 ft, Diffusers located 1.5 ft above tank bottom

Effect of DO on Aeration Efficiency

DO Conc, mg/L	Aeration Efficiency
1.0	115%
2.0	100%
3.0	84%
4.0	69%
5.0	53%

Goal of Our Energy Team

- Determine actual oxygen requirements
  - Dr. Moore's model
- Determine field transfer rate of aerators
  - Use previous data
- Optimize aeration use to satisfy oxygen needs efficiently
- Use on-off operation of aerators to achieve nitrification-denitrification and save energy